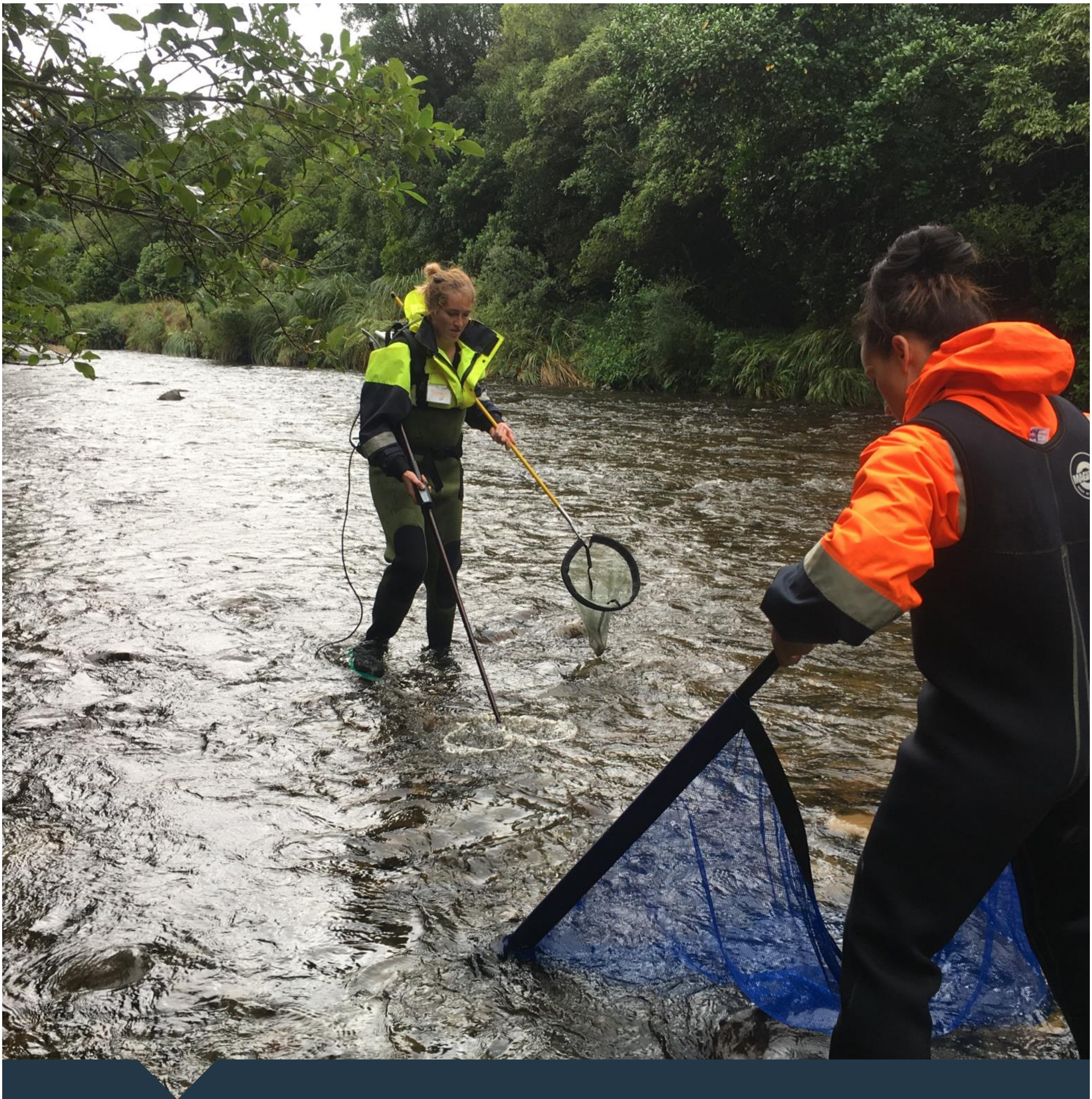

Salt intrusion after removal of a weir

May 2020

horizons
REGIONAL COUNCIL

Prepared for:

Logan Brown
Freshwater & Partnerships Manager

May 2020
Report No. 2020/EXT/1691
ISBN 978-1-99-000927-3

Prepared by:

Eleanor Gee
Michael Allis

National Institute of Water& Atmospheric Research Ltd
PO Box 11115
Hamilton 3251

www.niwa.co.nz

Salt intrusion after removal of a weir

Prepared for Horizons Regional Council

May 2020

Prepared by:
Eleanor Gee
Michael Allis

For any information regarding this report please contact:

Eleanor Gee
Hydroecologist
Freshwater and Estuaries
+64-7-856 1710
eleanor.gee@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

NIWA CLIENT REPORT No: 2020118HN
Report date: May 2020
NIWA Project: ELF20210

Quality Assurance Statement		
	Reviewed by:	Iain MacDonald
	Formatting checked by:	Alison Bartley
	Approved for release by:	Cindy Baker

Contents

Tables

Figures

Executive summary

The removal and remediation of barriers to fish passage is a growing concern in New Zealand and one which Horizons Regional Council (Horizons) is actively addressing in their region. Many New Zealand freshwater fishes are amphidromous and require passage from the sea as juveniles to access suitable adult habitat further upstream in the catchment. The Akitio River on the East Coast of the North Island has two significant historical weirs, with the lower weir being in the tidal zone. Horizons is considering the removal of the weir to mitigate the barrier it provides to fish passage. It is necessary, however, to consider concerns from landholders about the potential impact on upstream water quality due to possible increased saline intrusion. NIWA was contracted to estimate the upstream extent of saline intrusion if the weir was to be removed, based on a desktop review followed by prescribing and overseeing field observations and then interrogating the data collected.

The desktop review could not ascertain the likely extent of current saline intrusion. There were gaps in the data available and slightly contradictory reports of the upstream extent of saline intrusion. Therefore, a site visit was necessary to provide more information to help estimate the current upstream saline extent and to predict the effect of removing the weir.

The timing of monitoring was chosen to obtain an estimate of the maximum upstream saline extent under average conditions (i.e., excluding short-term events such as storm surges). To this end, the survey was conducted on January 16, 2020 during a period of low flow and spring tides.

Brackish water extended to the weir, although the upper part of the water column at the weir was fresh. Salinity at the bed decreased longitudinally and was below 5 psu in the vicinity of the weir. A tidal water level signal was seen at the weir. No geologic controls on saline intrusion exist below the weir. The mudstone sill on which the weir is built provides a partial geological control, however its height and width are unknown.

The removal of the lower weir is expected to increase the extent of saline intrusion to between 100 m and 2 km upstream of the existing lower weir under present conditions. The removal of the weir will affect upstream water levels and eventually a tidal signal will be seen to around 2 km upstream of the weir, as compared with the existing ~ 4.6 km of backwatering due to the weir. In the far future (i.e., around 2120), rising sea levels and vertical land movement in the Akitio area are predicted to lead to an increase in the upstream extent of saline intrusion of the order of 6 km or more (upstream of the existing weir).

The lower weir is built on an existing outcrop of mudstone. It is unclear to what extent this would continue to provide a barrier to saline intrusion after the removal of the man-made weir sitting atop it.

The removal of the weir would benefit fish passage and be of greatest benefit to īnanga and smelt, which are completely excluded from upstream passage by the weir. Given that an extra 2 km of upstream river would experience a tidal signal after the removal of the weir, the removal may also open up extra spawning area for īnanga. The presence of the rabbit weir a further 41 km upstream of the lower weir does not significantly mitigate the benefits of removing the lower weir.

1 Introduction

1.1 Background

Addressing barriers to fish passage is a growing piece of work for Regional Councils across New Zealand. The recent (September 2019) Proposed National Environmental Standards (NES) for Freshwater specifically seeks to ensure fish that need migratory pathways to the sea face fewer barriers. Horizons Regional Council has an active programme to restore fish passage throughout the region's catchments.

The Akitio River on the East Coast of the North Island has two significant historical weirs, with the lower weir being in the tidal zone of the river (Figure 1-1, Table 1-1). The weirs are both situated on the mainstem of the river and are resulting in significant impediment to fish passage within the entire Akitio catchment (Logan Brown, Horizons Regional Council, pers. com.). The lower weir, at the time of installation, was installed to prevent saltwater intruding inland to a point where it prevented river water being taken for stock water and irrigation. The second weir is further inland and was installed as a rabbit weir (to stop the spread of rabbits). Horizons is considering the removal of the lower weir (and eventually the upper weir) as part of its fish passage restoration programme, to restore the migratory paths of native fishes. However, concern has been raised about how far inland the saltwater will migrate if the lower weir is removed and therefore the potential impact on the taking of fresh water for stock water and irrigation purposes. Horizons therefore approached NIWA to provide specialist scientific advice to help develop plans for field observations, undertake the observations, and interpret the results to provide advice about the likely upstream extent of saline intrusion.

Table 1-1: Locations of the lower and upper weirs on the Akitio River, and their distance upstream of the mouth.

Site	Easting, NZTM (Lat, WGS84)	Northing, NZTM (Long, WGS84)	Distance upstream of mouth (km)
Lower weir (downstream weir)	1887828 (176.39967254)	5504285 (-40.56219185)	8
Upper weir (upstream weir)	1880223 (176.30361075)	5518717 (-40.43499794)	49

Figure 1-1: Locations of the lower and upper weirs on the Akitio river.

1.2 Scope

This project sought to provide advice and a report that answered two questions:

1. does the saltwater wedge currently make it to the base of the weir, and
2. if it does make it the base of the weir, how far inland will the saltwater wedge intrude once the weir is removed?

The tasks to deliver the advice comprised:

1. a desktop review of available hydrometric, bathymetric and topographic data to estimate the current upstream extent of saline intrusion, and to provide a monitoring plan to verify the estimate

2. a site visit to oversee the monitoring to verify the estimate of saline intrusion extent

3. projections based on topography and bathymetry of the upstream extent of saline intrusion after weir removal, and

4. a brief report documenting the findings.

2 Desktop review and prediction of saline intrusion extent

Saline intrusion into an estuary is influenced by estuarine bathymetry, tidal amplitude and river flow (Prandle 2009). As a starting point, the slope of the river bed places a limit on the upstream extent of saline intrusion. In the absence of freshwater flowing down the river, the sea water can only extend upriver to the point where the bed elevation is equal to level of the sea surface at any given time (allowing for a time lag for the tidal wave to propagate upstream).

The hydraulic force balance between the upstream flood tide from the sea and the downstream river flow also affects the upstream extent of saline intrusion. The balance is influenced by mixing between the saltwater layer and the freshwater layer. Turbulence at the interface of these water bodies is generated by bed friction, the wave associated with the flood tide of sea water, the downstream flow of freshwater, wind effects and the Coriolis force (Dyer 1997). The degree of mixing at this interface is therefore difficult to predict and subject to variation on short and long time scales. The degree of mixing not only influences the upstream extent of saline intrusion but also the vertical salinity profile in at any given point in the estuary. If there is little mixing a vertically layered profile persists in which the more dense saline water sits below the less dense fresh water and a vertical gradient of salinity exists as well as a longitudinal one. During times of greater mixing there is a breakdown in the vertical structure and salinity varies mainly along the longitudinal axis of the estuary.

The upstream extent of saline intrusion into an estuary is difficult however, to predict analytically (Prandle 2009). Theories of saline intrusion rely on measurements of tidal propagation, velocities, and river inflows over a range of tide and flow conditions (Prandle 2009). For the purpose of this study however, the temporal variability in the intrusion length is unimportant as we are interested in the greatest extent of upstream saline intrusion. This represents the worst case scenario for water quality limits on the consumptive and agricultural uses of water. Here we have considered the greatest extent of upstream saline intrusion under “normal” conditions. In other words, we have considered seasonal variability due to hydrological events and more frequent variability due to tidal cycles, but have not accounted for short-term episodic events such as storm surges.

2.1 Data collation

The data collation included obtaining hydrographic data and modelling for the Akitio catchment, reviewing topographic information available from LINZ, and reviewing relevant reports on previous monitoring or studies undertaken in the Akitio catchment.

Relevant literature and reports were collated relating to the Akitio River and, in particular, the lower 20 km as such reports might provide relevant information about the extent of upstream salt intrusion in the presence of the weir or before the weir was first built. Three relevant reports were identified, one of which provided a description of the estuary and the other two of which provided relevant background information about the Akitio catchment and weir.

Flow records for the Akitio River at Waihi (~41 km upstream of river mouth) were obtained for the period March 2019 to January 2020 (Horizons Regional Council 2020). Flow records were compared with national-scale statistically generated hydrological estimates from NZ River Maps (Booker and Whitehead 2017). These data were used to provide an indication of the magnitude of influence of river flow on the extent of saline intrusion, and also to understand the hydrological conditions that occurred at the time of the subsequent site visit.

Tidal predictions from LINZ were obtained for the nearest river mouths where such predictions are available – Napier, to the North of Akitio, and Castlepoint, to the South. These were used to predict the likely tidal fluctuation at the mouth of the Akitio River, noting that the amplitude of tidal fluctuations is typically damped inside river mouths and decreases the further upstream a site is from the river mouth. Unfortunately, no data on tidal water level fluctuations were available inside the Akitio estuary.

None of the available reports or data provided sufficient information to accurately estimate the upstream extent of saline intrusion however, the relevant information is reported in the following section along with some estimates of the upstream intrusion distance.

2.2 Findings

The Akitio River originates 9 km North-North East of Weber and flows approximately 70 km to the Pacific Ocean at the Akitio settlement on the East Coast. The catchment flows through predominantly pastoral land (Manawatu-Wanganui Regional Council 1997). The main tributaries include Mangahewa Stream, Mangaone Stream, Makukupara Stream, Waihi Stream, Tahuokaretu Stream, Mangato Stream, Red River and Riddley Stream. This provides a total catchment size of approximately 600 km^2 (Veale 2005). The lower reach of the Akitio flows through alluvial flats, has a trapezoidal channel, and the bed is composed of fine mobile sediment and stabilised by outcrops of mudstone and by the two weirs (Veale 2005). The construction of the lower weir raised upstream water levels by 6 ft (1.8 m) (Veale 2005).

The lower river has recreational value for canoeing, swimming and fishing (Manawatu-Wanganui Regional Council 1997), including whitebaiting (Robertson and Stevens 2016). The inclusion of whitebaiting amongst the noted recreational values for the lower catchment indicates the potential for upriver migration of juvenile īnanga and smelt if the weir (which currently impedes passage of non-climbing fishes) were to be removed.

Bed slope is a useful indicator of the theoretical maximum upstream limit of saline intrusion because, in the absence of a freshwater flow gravitational forces dictate that sea water will not, on average, progress further inland than the point at which the land elevation is equal to the height of the sea on a spring high tide. This is a simplification excluding tidal dynamics, but is a useful starting point for estimating the likely upper saline extent. Two estimates were made of the average slope of the river bed. The lower 50 km of the river falls approximately 39 m (Veale 2005), giving an average bed slope of 0.8 m/km. This concurs with the estimate derived from the 1:50,000 scale topographic map with vertical contours of 20 m, which gives a fall of 20 m over the lower 26 km of the river, or 0.8 m/km (LINZ 2014). Over the course of the lower 50 km of the river, large variations in the slope of individual reaches can occur. Typically, lowland reaches are flatter than upland reaches, therefore, it is likely that the river bed slope downstream of the weir is less than this estimate of average slope. This means that the theoretical upstream extent of saline intrusion is likely to extend further than would be predicted by the average river slope over the lower 50 km.

Flow records are available for the Akitio River at Waihi near SH52 (48 km upstream), however there are no flow records for the lower reaches of the river. Predictions are available for all stream reaches nationally, using statistical modelling, at NZ River Maps (Booker and Whitehead 2017). These estimates are indicative only however, they give an idea of the scale of hydrological influence on saline intrusion – a river with higher flows will have less saline intrusion for the same tidal range and bathymetry than a river with lower flows. Predictions for the reach of the Akitio on which the lower weir is located are for a median flow of around 4 m^3/s and a 7-day mean annual low flow (MALF) of around 1 m^3/s. Even accounting for the considerable uncertainty in these estimates, they indicate that there is little hydraulic influence from the riverine flows on the upstream extent of the saline influence in a river of this size.

On the flooding tide, a gradient in water levels between the sea and the river provides the hydrostatic force which drives the incursion of saline water upstream. Sea level varies on both the short and long term due to tidal fluctuation, meteorological events (e.g., storm surge), geological events (e.g., earthquake causing tsunami), and climatic changes. In this assessment we restrict consideration to tidal fluctuations and to predicting the influences of sea level rise and the vertical land movement on the future saline intrusion. Influences on future saline intrusion are discussed in Sections 4.2 and 4.3.

In terms of tidal influence: during spring high tides, sea levels are typically at their largest, which in turn results in the greatest extent of upstream saline intrusion. There are no tide predictions for directly outside the mouth of the Akitio River, however LINZ (2019) publishes predictions for Napier to the North and Castlepoint to the South, and publishes a predicted time offset (but no height) for the Akitio River mouth. High spring tide raises water levels to around 1.9 m above lowest astronomical tide (LAT) at Napier, while at Castlepoint spring high tide raises water levels to about 1.7 m above LAT On average, therefore, spring high tide outside at the mouth of the Akitio is approximately 1.8 m above LAT. At the port of Napier, LAT is at -1.147 m NZVD16 (LINZ 2018), which means that spring high tide at Akitio is around 0.65 m NZVD16.

To estimate the effect of the tide, we need to know the height of the stream bed with reference to the same datum as the tidal predictions, how much the tidal signal is attenuated through the mouth of the estuary, and the average slope of the river bed. Unfortunately, none of this information was available from the reviewed literature. In light of this, the following was assumed. Firstly, we assume that no attenuation of the tide-signal occurs along the river . Robertson and Stevens (2016) give the mean depth of the estuarine reach as 1.1 m, although the tidal conditions at the time are not noted. For the sake of a conservative estimate, we can assume the depth is on average 1.1 m at the mouth below lowest astronomical tide, which gives a sea level of 2.9 m relative to the bed at spring high tide. Based on these estimates and the average bed slope of 0.8 m/km we would expect saline intrusion to between 3 km and 4 km upstream.

In contrast to this estimate, the length of the estuarine reach was reported by Roberston and Stevens (2016) as 7 km, i.e., about 1 km short of the lower weir. Veale (2005) noted, however, that the weir was originally constructed to prevent further upstream saline intrusion, which suggests that saline water may extend as far upstream as or even further upstream than the weir. Robertson and Stevens (2016) note the potential for vertical stratification (i.e., saline water sits in a distinct layer below the fresher surface water) under low baseflow conditions. This implies that at the times when saline intrusion is furthest upstream (due to lack of opposing river flow) the saline water may nonetheless be limited to the lower part of the water column.

2.3 Monitoring plan

The gaps in the data available as part of the desktop review and the contradictory reports of the upstream extent of saline intrusion given in Robertson and Stevens (2016) and Veale (2005), and the difference between their estimates and our estimate based on topography highlighted the need for a site visit to provide more information from which to estimate the current upstream saline extent and to predict the effect of removing the weir.

The timing of monitoring was chosen to obtain an estimate of the maximum upstream saline extent, which is likely to occur during spring-tides and low flows conditions. To this end, the survey was planned to occur during the summer low flow period, preferably not after recent rain, and on a spring high tide. January 16th 2020 was chosen as a date that met these conditions as well as the logistical need for daylight. High tide on January 16th occurred at approximately 0900 NZST at the Akitio mouth (LINZ 2019).

The plan for the monitoring consisted of the following:

- Start monitoring around the time of high tide at the mouth.
- Travel upstream in a boat, measuring salinity near the bed (in case of stratification) at approximately 500 m increments until the upstream extent is located. Note this location.
- Measure the vertical salinity profile at this location to establish whether vertical saline stratification is present.
- Repeat salinity measurements in the vicinity of the previously noted upstream extent to check whether the saline intrusion is continuing to progress upstream over time. If it does, then revise the noted location of the upstream extent of saline intrusion accordingly. Continue this process until the saline water starts to ebb downstream.
- Repeat the measurements of vertical stratification at approximately 1 km and 2 km downstream of the upstream saline extent to assess the longitudinal and vertical salinity structure.
- Measure the depth of the thalweg from the weir downstream to the mouth, to understand the possible impact of bathymetry on the current extent of saline intrusion and the likely intrusion after the removal of the weir.
- Measure the height of the weir.
- If access to the river by boat is possible upstream of the weir, measure the depth of thalweg from the weir upstream for some distance depending on the observed extent of saline intrusion on the day of monitoring.
- Observe the extent of backwatering above the weir.

3 Site visit and monitoring to estimate of saline intrusion extent

3.1 Site visit

The site visit was conducted on January 16, 2020. In the lead up to the site visit, the rainfall gauge at Akitio registered a cumulative 17 mm of rain on January 13 between 2 pm and 10 pm. There was no evidence on the day of monitoring that this rainfall was affecting flow, and it would not be expected to do so after 2 days. On January 16 there was a daily average flow of 0.136 m^3s^{-1} measured at Waihi at SH52, which is in the range of summer low flows.

Staff from NIWA and Horizons Regional Council jointly undertook the monitoring, with Horizons staff skippering the boat, undertaking surveying, and providing the conductivity, temperature, and salinity (CTD) probe with which the salinity measurements were made. Vertical salinity profiles were measured using a recently calibrated Aquatroll CTD. Salinity profiles were measured from 2.9 km upstream of the river mouth up to the weir. A real-time kinematic GPS was paired with a depth-sounder to survey the thalweg from the weir to 375 m upstream of the high-tide mark at the mouth (horizontal accuracy 0.5 cm, vertical accuracy 1.0 cm). Raw survey data was processed by Horizons Regional Council staff. Changes in water level throughout the survey were accounted for. The weir was measured at 8.175 km upstream of the mouth. The river was not accessible for surveying upstream of the weir, but the location of the upstream extent of backwatering from the weir was noted from previous observations of water surface profiles under similar flow conditions (0.143 m^3s^{-1} on December 5, 2019) made by a geomorphologist and staff from Horizons to provide a guide as to the average bed slope upstream of the weir.

Figure **3-1** and Figure 3-2 show the true left and true right sides of the weir, respectively. In

Figure 3-1 the exposed part of the mudstone sill which underlies the weir can be seen, protruding to the height of the crest in one spot.

Figure 3-1: The lower weir viewed from downstream and the true right bank. Note the mudstone sill which underlies part of the weir and protrudes to the height of the weir crest in one place.

Figure 3-2: The lower weir viewed from downstream and the true left bank.

3.2 Salinity

Salinity profiles are given in Figure 3-3. In keeping with the convention of plotting a river longitudinally left to right from upstream to downstream, the weir is located at the 8.175 km mark on the left side of the x-axis in all figures. Surface and bed salinity had similar patterns longitudinally – increasing as expected towards the sea and decreasing in the upstream direction. The surface salinity decreased from 30 psu (practical salinity units, equivalent to parts per thousand in the range discussed in this report) to 0 psu along the length of the estuary from mouth to the weir. By contrast the bed salinity also decreased , but at a lower rate than the surface salinity, from 32 psu near the mouth to between 15 and 20 psu between 7.2 and 7.9 km upstream of the mouth. Upstream of that point the bed salinity dropped sharply to below 10 psu, then to 1-2 psu at the weir.

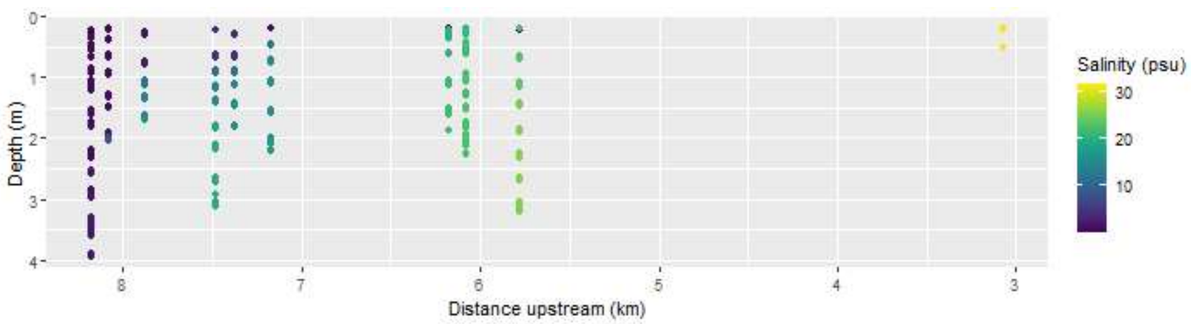

Figure 3-3: Salinity (psu) variation with distance and depth.

Figure 3-4 shows an interpolation of the vertical salinity profiles measured at various points along the upper 5 km of the estuary. While there is noise in the data, the shading and isohalines show that there is some vertical salinity stratification, with water on the surface that is fresher than near the bed. There is also a clear longitudinal gradient with salinity around 30 psu[1], 3 km upstream from the mouth decreasing to < 2 psu at the weir.

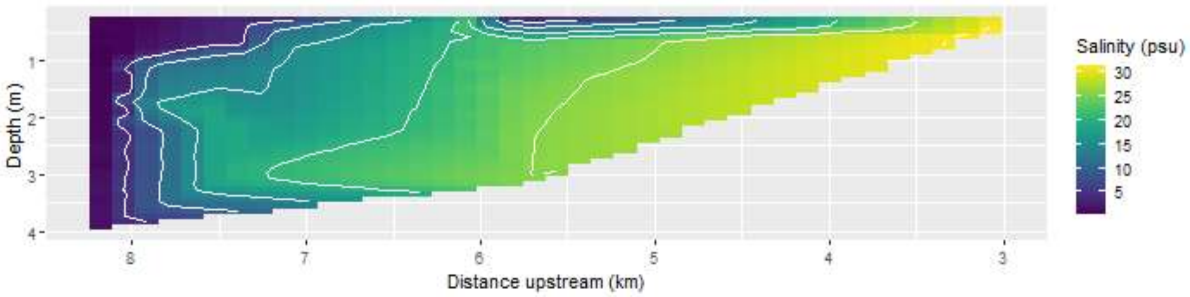

Figure 3-4: Salinity (psu) variation with distance along the estuary (km) and depth below the water surface (m). Contour lines show isohalines at 5 psu intervals. This graph is interpolated from the measured data shown in Figure 3-3.

As to the location of the upstream extent of the saline intrusion, "freshwater" is typically defined as water with salinity less than 0.5 – 2 psu depending on the context of the definition (e.g., Venice System 1958, Whitfield et al. 2012). In this instance we consider freshwater to be less than 1 psu. The part of the estuary where salinity was < 1 psu is highlighted in Figure 3-5 (colours other than yellow are < 1 psu). This reference point suggests that the upstream extent of saline intrusion is approximately at the lower weir. At the weir however, from an ecological perspective the water would be dominated by freshwater flora and fauna. Furthermore, at the weir, freshwater occupies the upper 2 m of the water column.

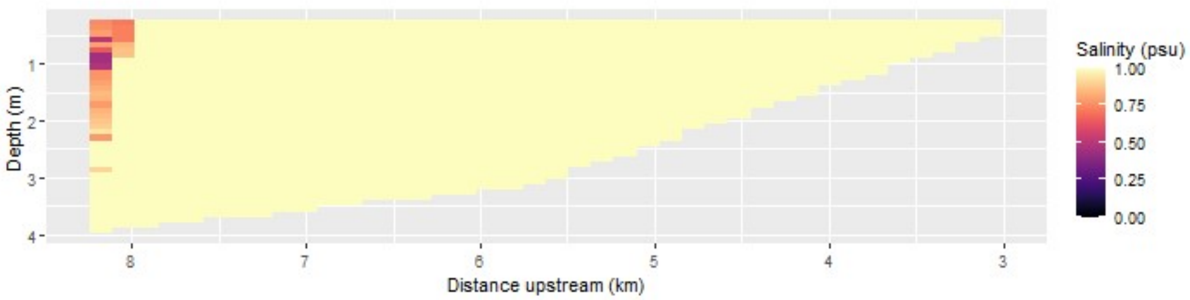

Figure 3-5: Salinity (psu) variation with distance along the estuary (km) and depth (m), highlighting where salinity is < 1 psu.

Using 1 psu as the reference point for the extent of saline intrusion, intrusion currently extends to the weir. With the removal of the weir it will extend slightly beyond the location of the weir. This is discussed further in Section 4.1 (Saline intrusion after weir removal under existing conditions).

[1] Oceanographic waters have a salinity of around 35 PSU

3.3 Bathymetry and water level

High tide at the weir occurred approximately 1 hour after high tide at the mouth. A water level of 0.73 m was observed at the weir. A long-section of the thalweg of the estuary is given in Figure 3-6. The observed high water level is marked in the figure with a dashed line. The bathymetric survey shows that the average bed slope from the mouth to the weir is close to zero. The hydraulic gradient is only 0.00001 m/km, based on a difference in water level of 8 cm over the 8 km from the mouth to the weir. This helps to account for the saline intrusion extending to the weir, which is significantly further than predicted by the average bed slope of the lower 26 km or 50 km of the river (see Section 2.2). The bathymetry does not show any large steps in the bed-profile, and in combination with the observed extent of saline intrusion this suggests there are no geologic controls on the upstream extent of saline intrusion through the lower section of the river up to the weir. The mudstone sill on which the weir was constructed may provide a control on the further upstream progress of saline water however, that would depend on the height of the sill, something that could not be ascertained during the monitoring.

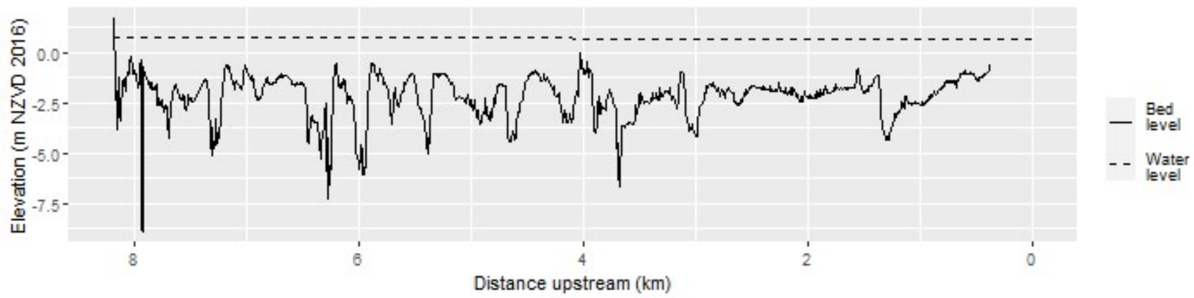

Figure 3-6: Long-section of the thalweg of the estuary. The observed high water level on the day of monitoring is shown as a dashed line.

The central low point of the crest of the weir was surveyed at 1.71 m NZVD16. Upstream of the weir, backwatering due to the presence of the weir extended approximately 4.6 km. This extent of backwatering due to a weir crest of 1.71 m NZVD16 gives an average hydraulic gradient (water level slope) of 0.37 m/km, which suggests that in the absence of the weir, a spring high tide water level of 0.73 m NZVD16 would cause tidal water level fluctuations to around 2 km upstream of the weir.

It is worth mentioning that immediately upstream of the weir the bed level was raised due to infilling of sediment behind the weir to approximately the height of the weir crest (see Figure 3-7). This infilled sediment will likely become a slug of sediment that will propagate downstream after the weir is removed. It is beyond the scope of this report to comment on the timing or nature of that sediment transport, however, it would likely impact the upstream backwatering, which would change over time as the sediment level drops.

Figure 3-7: The lower weir viewed from upstream. Note the infilling of sediment behind the weir.

3.4 General observations

Īnanga were observed around 1 km downstream of the weir (see Figure 3-8). This observation verifies the current presence of swimming native migratory fishes that should benefit from the removal of the weir.

Figure 3-8: Īnanga observed around 1 km downstream of the weir.

4 Predictions of saline intrusion extent after weir removal

4.1 Saline intrusion after weir removal under existing conditions

From the field observations, it is apparent that saline intrusion currently extends to the weir. While salinity in the top 2 m of the water column in the vicinity of the weir was < 1 psu and a surface layer of water < 5 psu exists for a kilometre downstream, the bed water is saline. Longitudinal variation in bed salinity is therefore likely to be the factor that determines the upstream extent of saline intrusion after the weir is removed. To determine the upstream extent of bed salinity, the measurements of bed salinity were plotted against distance upstream of a mouth and an exponential model was fitted to the data. The raw bed salinity data and the fitted model can be seen in Figure 4-1. The fitted model has an R^2 value of 0.89 and is statistically significant using a p-value threshold of 0.001. Using the fitted model to predict where salinity falls to < 1 psu gives an extent of 8.29 km upstream of the mouth (i.e., 115 m upstream of the weir).

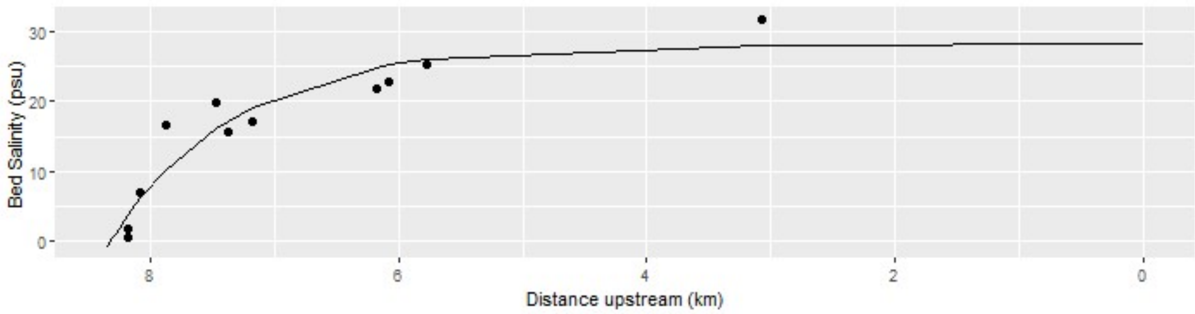

Figure 4-1: Bed salinity along the length of the estuary (•), with a fitted exponential model, $R^2 = 0.89$ (—).

The measurements of salinity were taken during low flows and spring high tide which, therefore, gives a good estimate of the furthest upstream extent of saline intrusion that regularly occurs. However, because salinity intrudes as far upstream as the weir, the possibility cannot be ruled out that freshwater becomes sandwiched between the flooding tide of seawater and the physical barrier of the weir. The removal of the weir will lead to tidal water level fluctuations up to around 2 km upstream of the current location of the weir. There may be some saline intrusion as far upstream as the tidal limit.

After the removal of the weir therefore, the extent of saline intrusion is expected to increase by a least 100 m and up to 2 km beyond the current location of the weir. This estimate does not consider the effect of the mudstone sill, as its profile is unknown and there may be a section of the weir were the sill does not underlie the weir.

4.2 Sea level rise

The recently published manual on coastal hazards and climate change (MfE 2017) has a number of strategies to manage hazard, and risk and vulnerability assessments. The manual compiles a range of sea level rise projections for NZ based on global Representative Concentration Pathway (RCP, i.e., greenhouse gas concentration) models and Intergovernmental Panel on Climate Change work (see figure below), with applicability based on the type of activity, and provides transitional New Zealand-wide sea level rise allowances and scenarios for use in planning instruments where a single value is required at a local/district scale. Within this, Category C generally covers existing development, while category D applies to short-lived, non-habitable assets and where consequences are low or readily adaptable. The minimum transitional sea level rise values of 0.65 m and 1 m respectively for these latter two categories are generally applicable towards the end of the next 100 years (e.g., up to 2120). On the basis that the proposed weir removal is in category C or D, a value of 1 m sea level rise above the 1986-2005 mean sea level is selected for this study. Note that this is 0.9 m above the present-day mean sea level (see Figure 4-2).

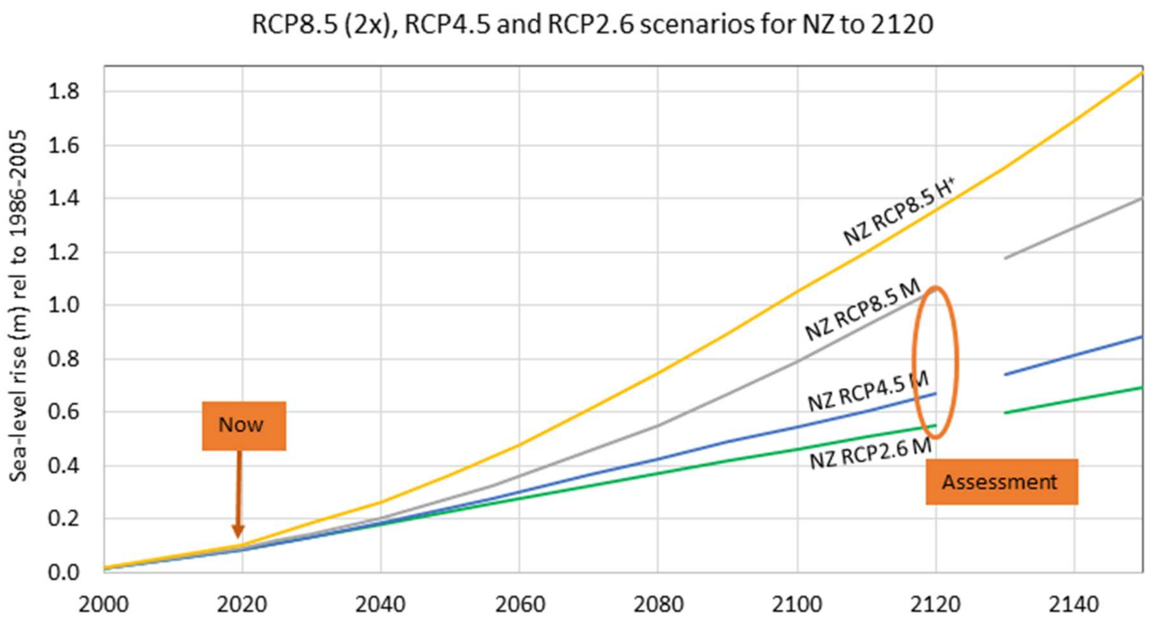

Figure 4-2: Projected sea level rise for various representative concentration pathways (RCPs) modelled for New Zealand (MfE 2017).

Notes:

1) The sea level rise values include a small additional component for the departure of sea level rise in the SW Pacific relative to the global mean projections.

2) No vertical land movement has been included.

3) H+ projection derived from Kopp et al. (2014) 83rd percentile – rest of projections are from IPCC AR5 (IPCC 2014) extrapolated to 2150 using slopes from Kopp et al. (2014).

4) Sea level rise zero baseline covers period 1986-2005 - centred on 1996.

4.3 Vertical land motion

Vertical land movement data have been collected at a continuous GPS (cGPS) site at Akitio since 2006 with the data accessible at the Geonet website (https://www.geonet.org.nz/data/gnss/map site AKTO). A 2012 national study or vertical land motion showed secular subsidence (long term, non-seismic) around 3.3 mm/year from 2006-2012 (see Table 2 in Beavan and Litchfield 2012 and Figure 4-3).

An update on vertical land motion was provided for the nearby Greater Wellington Region (Bell et al. 2018) which illustrates a continuation of the previously observed trend. In the 2018 study the nearest point to Akitio shows 3.81 mm/year secular subsidence (long term) (site: TRAV, 100 km south).

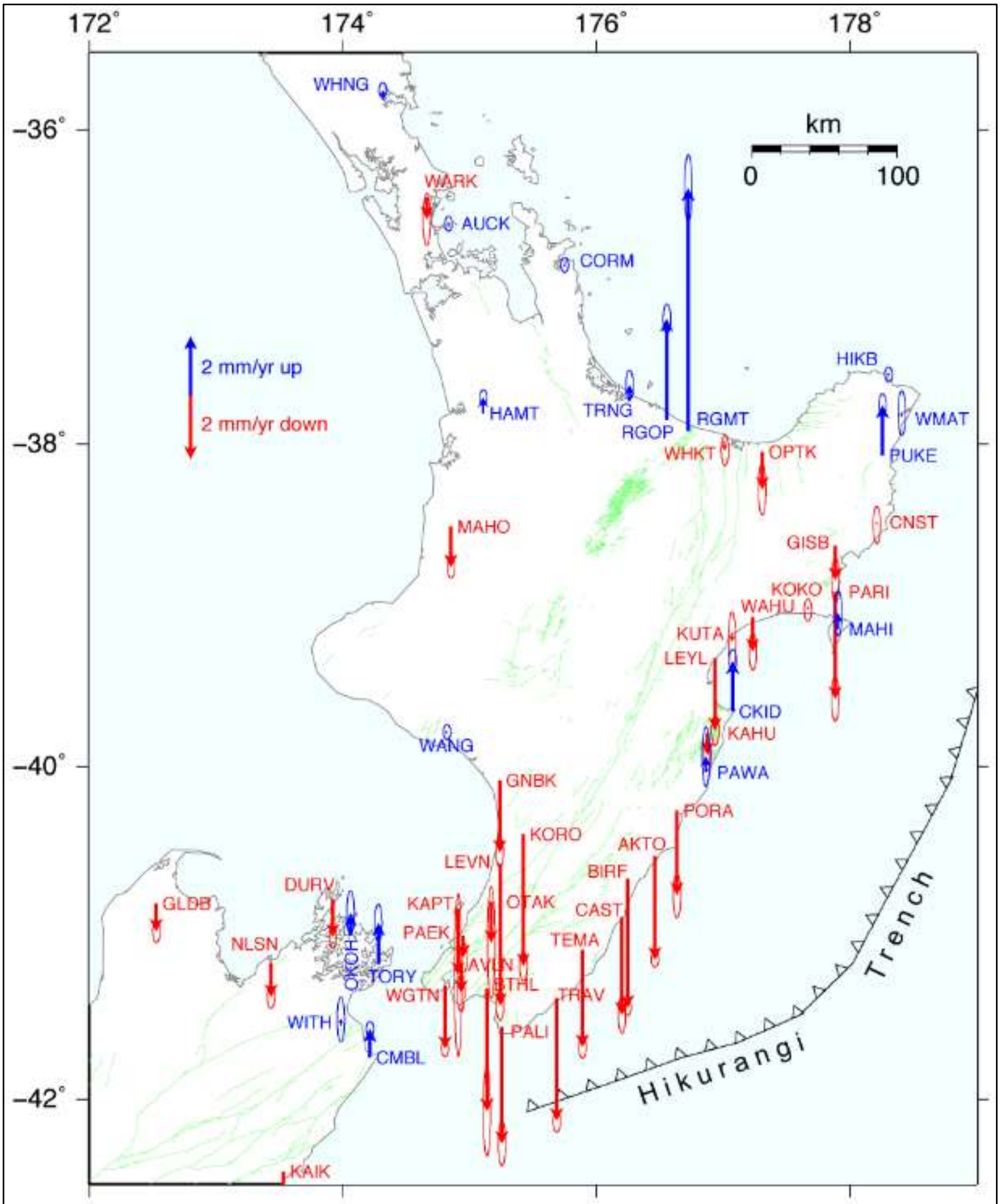

Figure 7 Present-day vertical rates estimated at near-coastal cGPS sites in the North Island and northern South Island. These show rates of land elevation change relative to some reference. In this case, sites in Northland, Auckland, Waikato, Otago and Southland have vertical rates that average close to zero. See Figure 6 for view of the whole country.

Figure 4-3: Vertical land motion estimates. Source: Beavan and Litchfield (2012).

To account for future coastal changes in a precautionary manner (Resource Management Act 1991, DOC 2010), when assessing environmental effects, we can extrapolate a nominal 3.5 mm/year, which compares favourably with the measured values in the range 3.3 to 3.81 mm/year, background subsidence rates out to 100 years. This results in an additional 0.35 m of relative sea level rise caused by the land falling relative to the sea. This should be added to any sea level rise estimates.

4.4 Overall future saline intrusion projections

Over the next 100 years the relative sea level rise (i.e., sea level rise + vertical land motion) is estimated to be around 1.35 m (1 m sea level rise + 0.35 m vertical land motion), based on our current best estimates.

This increase in relative sea level will drive saline waters further upstream. Generally, the saline intrusion upstream from rising sea levels is expected to scale linearly with sea level rise. For example, at Akitio, a rough estimate of bed slope gives a rise of 0 m over the 8 km from the mouth to the weir, followed by about 1 m over the subsequent 4.6 km (assuming water depth at the upstream extent of backwatering of ~ 0.7 m). Assuming the slope upstream of the weir continues past the upstream extent of backwatering, a rise of 1.35 m will result in approximately 6.2 km of upstream saline intrusion (beyond the current location of the weir) over the next 100 years.

Exceptions to this are where geologic controls (i.e., rock sills, gradient changes) interfere with saline intrusion pathways. The effect of the mudstone sill on which the lower weir is built is unknown as the height of the sill could not be ascertained during the monitoring. Future river and groundwater flows may also change as result of climate change.

There is not expected to be any change to tides, and minimal change to storm-surges and wave heights which could affect saline intrusion up the Akitio River.

5 Discussion and conclusions

5.1 Present and future saline intrusion

The removal of the lower weir is expected to lead to saline intrusion at least an extra 100 m and up to 2 km upstream of the current location of the weir. The removal of the weir will affect upstream water levels, lowering them considerably over time as the sediment slug upstream of the weir moves. Eventually, a tidal signal will be seen to around 2 km upstream of the weir, as compared with the existing ~ 4.6 km of backwatering.

In the far future (i.e., around 2120), rising sea levels and vertical land motion in the Akitio area are predicted to lead to an increase in the upstream extent of saline intrusion, we estimate the upstream extent to increase around 6 km beyond the current location of the weir.

The lower weir is built on an existing outcrop of mudstone. It is unclear to what extent this would continue to provide a barrier to saline intrusion after the removal of the man-made weir sitting atop it.

5.2 Fish passage implications

In addition to the īnanga observed during the monitoring, smelt, banded kōkopu, longfin and shortfin eels, common bullies, redfin bullies and giant kōkopu have all been observed in the catchment and are documented in the New Zealand Freshwater Fish Database. All of these species would benefit from the removal of the weir as its height and vertical face provide an impediment to swimming and would create difficulties for some climbing species. The removal of the weir would be of greatest benefit to īnanga and smelt which are swimming species and therefore are completely excluded from upstream passage by the weir. Given that an extra 2 km of upstream river would experience a tidal signal after the removal of the weir, the removal may also open up extra spawning area for īnanga which spawn in vegetation on river banks subject to tidal inundation.

5.3 Removal of the upper weir

After the removal of the lower weir, the rabbit weir upstream will still remain as a barrier to fish passage within the catchment. However, as it is a further 41 km upstream, a very large amount of the catchment would be opened by the removal of the lower weir and the remaining upstream weir therefore does not significantly mitigate the benefits.

5.4 Other considerations

One of the observations from the field trip was that a large amount of sediment had accumulated behind the weir to the extent that the bed level immediately behind the weir was at the level of the weir crest. The removal of the weir will free this sediment and form a sediment slug which will progress downstream over time. This will create ecological disturbance as it moves, which may affect fish populations in the river in the short term. The alternative would be to remove this sediment infilling at the same time as the weir is removed.

6 Acknowledgements

Many thanks to the staff at Horizons Regional Council for their involvement in this project, particularly in the data collection and processing. Thanks to Logan Brown, Quentin Gilkinson, David Brown, and Wibo De Jonge.

7 References

Beavan, R.J., Litchfield, N.J. (2012) Vertical land motion around the New Zealand coastline: implications for sea-level rise. *GNS Science Report 2012/29,* GNS, Lower Hutt: 41.

Bell, R.G., Denys, P., Hannah, J. (2018) 18 January 2019 11.43 a.m. Update on relative sea-level rise and vertical land motion: Wellington region. Prepared for Greater Wellington Regional Council, *NIWA Report* 2019007HN, NIWA, Hamilton.

Booker, D.J., Whitehead, A.L. (2017) NZ River Maps: An interactive online tool for mapping predicted freshwater variables across New Zealand. *NIWA,* Christchurch. https://shiny.niwa.co.nz/nzrivermaps/

Department of Conservation (DOC) (2010) *New Zealand Coastal Policy Statement 2010*. Department of Conservation, Wellington.

Dyer, K.R. (1997) *Estuaries - A physical introduction*. 2nd ed. John Wiley & Sons, Chichester.

Horizons Regional Council (2020) *Envirodata flow records for Waihi.* https://envirodata.horizons.govt.nz/?siteName=Waihi%20at%20S.H.52&collectionName=Flow

IPCC (2014) *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland: 151.

Kopp, R.E., Horton, R.M., Little, C.M., Mitrovica, J.X., Oppenheimer, M., Rasmussen, D.J., Strauss, B.H., Tebaldi, C., (2014) Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future,* 2: 383–406. https://doi.org/10.1002/2014EF000239

Land Information New Zealand (LINZ) (2014) *Topo50 Digital topographic map no. BN37 – Akitio.*

Land Information New Zealand (LINZ) (2018) Local Mean Sea Level datums. https://www.linz.govt.nz/data/geodetic-system/datums-projections-and-heights/vertical-datums/local-mean-sea-level-datums, accessed April 2020.

Land Information New Zealand (LINZ) (2019) Tide predictions. https://www.linz.govt.nz/sea/tides/tide-predictions, accessed November 2019.

Manawatu-Wanganui Regional Council (1997) Proposed Regional Plan for beds of rivers and lakes and associated activities. Manawatu-Wanganui Regional Council, Palmerston North.

Ministry for the Environment (MfE) (2017) Coastal hazards and climate change: Guidance for local government, Ministry for the Environment, Wellington.

Ministry of Health (2018) Drinking-water Standards for New Zealand 2005 (revised 2018). Ministry of Health, Wellington.

Mitchell, P.M. (1998) *Low flows of the Akitio and Oawahanga Catchments.* Victoria University of Wellington, Wellington.

Prandle, D. (2009) *Estuaries: Dynamics, mixing, sedimentation and morphology*. Cambridge University Press, Cambridge.

Remane (1934) Die Brackwasserfauna. Verhandlungen Der Deutschen Zoologischen Gesellschaft, 36: 34 e74.

Robertson, B., Stevens, L. (2016) Manawatu-Wanganui Region Estuaries - Habitat mapping, vulnerability assessment and monitoring recommendations related to issues of eutrophication and sedimentation. Wriggle Consulting, Nelson.

Resource Management Act (1991).

Veale, D. (2005) Akitio River investigation of flooding and erosion potential: draft 2. *Manawatu-Wanganui Regional Council*, Palmerston North.

Venice System (1958) Symposium on the classification of brackish waters, Venice April 8–14, 1958. *Archives Oceanography and Limnology,* 11, Suppl: 1–248.

Whitfield, A.K., Elliott, M., Basset, A., Blaber, S.J.M., West, R.J. (2012) Paradigms in estuarine ecology – A review of the Remane diagram with a suggested revised model for estuaries. *Estuarine, Coastal and Shelf Science,* 97: 78–90. https://doi.org/10.1016/j.ecss.2011.11.026

horizons
REGIONAL COUNCIL

horizons.govt.nz

24 hour freephone 0508 800 800
fax 06 952 2929 | **email** help@horizons.govt.nz
Private Bag 11025, Manawatu Mail Centre, Palmerston North 4442